Polar Ozone Loss in a Changing Climate

Matthias Brakebusch[1], Cora E. Randall[1], Douglas E. Kinnison[2], Simone Tilmes[2], Michelle L. Santee[3]

[1]Laboratory for Atmospheric and Space Physics & Dept of Atmospheric and Oceanic Sciences, University of Colorado at Boulder, USA
[2]Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado, USA
[3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

SUMMARY

The goal of this work is to robustly simulate polar ozone (O_3) variability during recent years by optimizing a version of the passive ozone subtraction technique. The eventual goal is to predict future polar O_3 loss in a changed climate, and to explore how the atmosphere responds to polar ozone recovery. The passive O_3 subtraction technique subtracts simulated, inert (or partially inert) O_3 from observed or predicted ozone. The work here uses the Specified Dynamics Whole Atmosphere Community Climate Model (SD-WACCM) to simulate a "pseudo"-passive O_3 tracer which only non-halogen chemistry is allowed to perturb. Observations are from the Aura Microwave Limb Sounder (MLS). O_3 loss calculations during Arctic winter 2004/05 are in good agreement with previous work, providing an initial verification that SD-WACCM is appropriate for these types of studies. Diagnostic comparisons to observations of ozone-related species point to minor deficiencies in SD-WACCM simulations of descent and/or mixing, as well as halogen-induced O_3 depletion.

METHOD

- Three model simulations:
  - full-ozone chemistry
  - gas-phase-ozone chemistry only (pseudo-passive tracer)
  - no ozone chemistry (passive tracer, for reference)
- **I**nferred **L**oss: O_3 loss quantified by model & measurement
  IL = (EOS MLS O_3) – (SD-WACCM pseudo-passive O_3)
- **M**odeled **L**oss: O_3 loss quantified by model only
  ML = (SD-WACCM O_3) - (SD-WACCM pseudo-passive O_3)

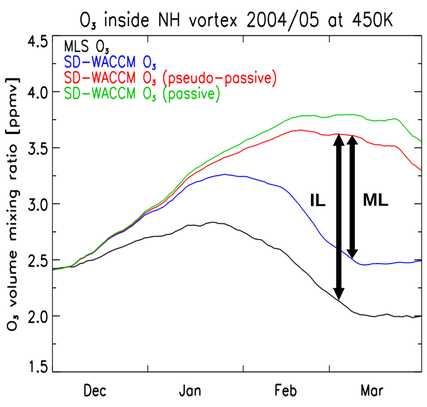

Figure 1: Evolution of observed ozone (black), modeled ozone (blue), modeled pseudo-passive ozone (red), and modeled passive ozone (green).

DATA

- EOS MLS on Aura (since August 2004), version 2.2
- SD-WACCM (nudged daily with GEOS* U, V, T), version 3548
  *Goddard Earth Observing System, reanalysis, version 5

INITIALIZATION

Global O_3, nitrous oxide (N_2O), nitric acid (HNO_3), hydrogen chloride (HCl), and water vapor (H_2O) initialized with MLS data

- On 1 Dec: before first O_3 loss occurs
- MLS data interpolated to SD-WACCM grid
  - Interpolation done on SD-WACCM pressure levels
  - Delaunay-Triangulation
  - Equal-area smoothing
- Cannot treat diurnal variations (e.g. chlorine monoxide (ClO))

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Contact: brakebusch@lasp.colorado.edu

COMPARISON OF MEASURED AND MODELED O_3 & O_3 LOSS

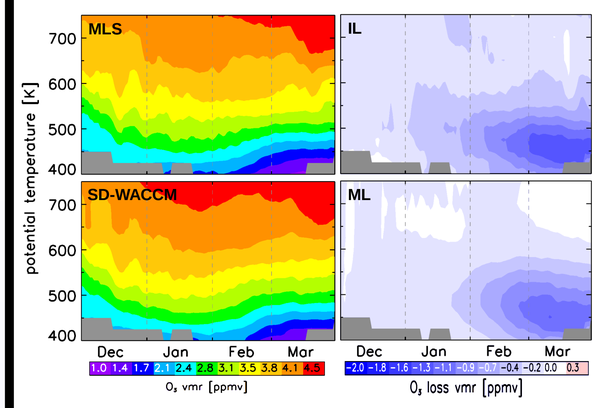


Figure 2: Evolution of vortex averaged (sPV > $1.6{\cdot}10^{-4}s^{-1}$) O_3 (left) from MLS (top) and SD-WACCM (bottom) and O_3 loss (right) for IL (top) and ML (bottom). Compensation of errors in descent and/or mixing by errors in O_3 loss (see below) leads to excellent agreement of O_3 from MLS and SD-WACCM.

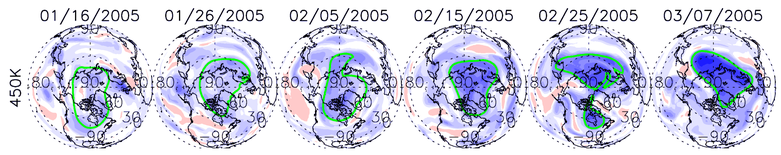


Figure 3: Spatial distribution of inferred O_3 loss at 450K in 10day intervals throughout the season (same color bar as Fig. 2) with a green $1.6{\cdot}10^{-4}s^{-1}$ sPV contour. Largest O_3 loss of 2ppmv occurs at the end of the season.

Table 1: Comparison of shown O_3 loss results (last column) with previous research.

Potential Temperature	Manney et al. [2006]	Jin et al. [2006]	Rex et al. [2006]	Rösevall et al. [2008]	Singleton et al. [2007]	MLS/WACCM
400K		0.8 ppmv	1.6 ± 0.3 ppmv	0.7 ppmv	1.4 ppmv	0.6 ppmv
450K	1.2 - 1.5 ppmv	2.0 ppmv	1.7 ± 0.4 ppmv	1.3 ppmv	2.2 ppmv	1.3 ppmv
500K	1.2 - 1.5 ppmv	2.1 ppmv	1.1 ± 0.4 ppmv	0.8 ppmv	1.8 ppmv	1.0 ppmv
550K		1.2 ppmv	0.6 ± 0.3 ppmv	0.5 ppmv	1.3 ppmv	0.5 ppmv
600K		0.6 ppmv		0.4 ppmv	0.6 ppmv	0.3 ppmv

COMPARISON OF MEASURED AND MODELED N_2O

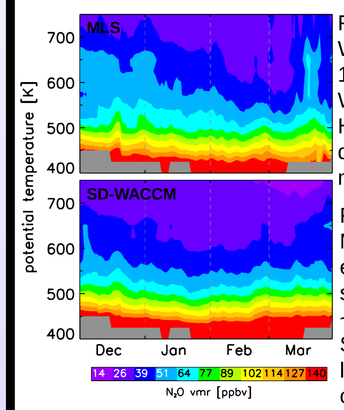
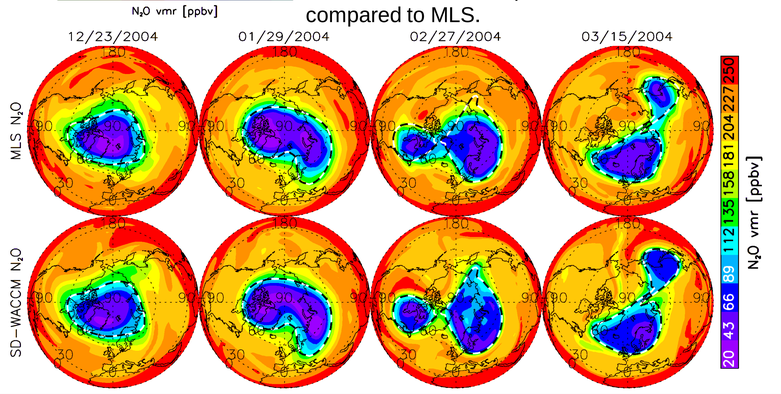


Figure 4 (left): Evolution of MLS (top) and SD-WACCM (bottom) vortex averaged N_2O (sPV > $1.6{\cdot}10^{-4}s^{-1}$). Differences indicate errors in SD-WACCM simulation of descent and/or mixing. However, no clear distinction between differences in descent and mixing across the vortex edge can be made.

Figure 5 (below): Spatial distribution of N_2O (1st row MLS, 2nd row SD-WACCM) at 490K for one day each month throughout the season with a $1.6{\cdot}10^{-4}s^{-1}$ sPV line contour. The final warming happened ~3/10 [Manney et al., 2006]. Differences between SD-WACCM and MLS N_2O mixing ratios suggest less descent inside polar vortex for SD-WACCM compared to MLS.



RELATED CHEMICAL DIAGNOSTICS

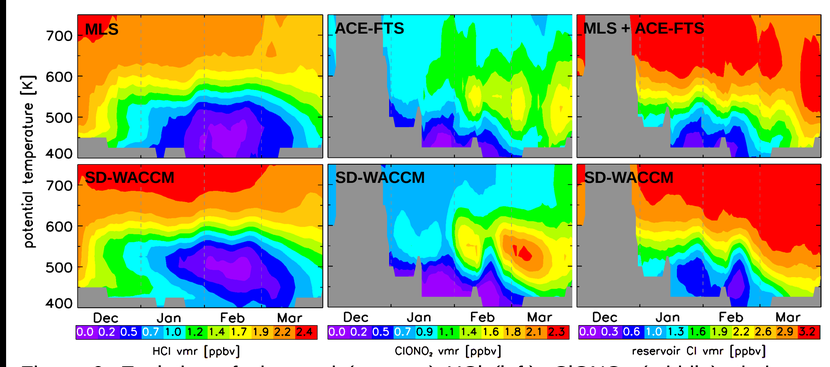


Figure 6: Evolution of observed (top row) HCl (left), $ClONO_2$ (middle), their sum (right) and SD-WACCM respectively (bottom row) inside the polar vortex (sPV > $1.6{\cdot}10^{-4}s^{-1}$). Cl in reservoir species from SD-WACCM compares well with observations, suggesting the correct partitioning of chlorine between reactive forms and reservoirs.

RELATED MICROPHYSICAL DIAGNOSTICS

Figure 7 (left): Evolution of polar vortex averaged (sPV > $1.6{\cdot}10^{-4}s^{-1}$) gas-phase HNO_3 from SD-WACCM (bottom) compares well with MLS (top). Slight underestimates in the model are found later in the season below ~550K.

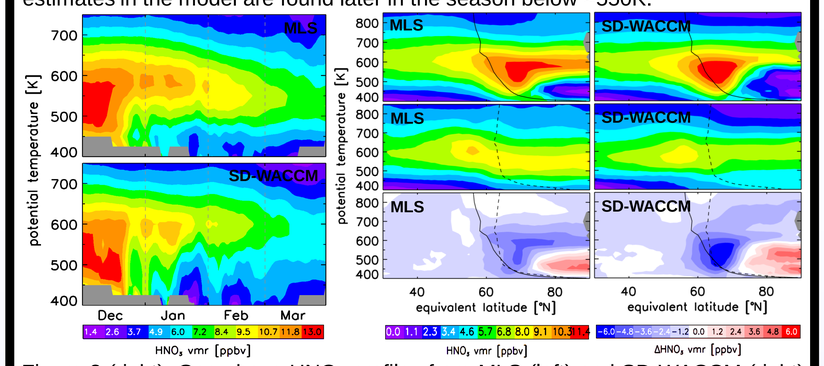


Figure 8 (right): Gas-phase HNO_3 profiles from MLS (left) and SD-WACCM (right) on 1/23 (top) and 3/10 (middle), and 3/10 minus 1/23 (bottom).

Too much uptake of gas-phase HNO_3 in SD-WACCM is consistent with too little $ClONO_2$ (see Fig. 6). Reasonable O_3 loss then suggests that PSC particle size distribution is shifted towards bigger radii (more uptake, same surface area).

POLAR VORTEX EDGE

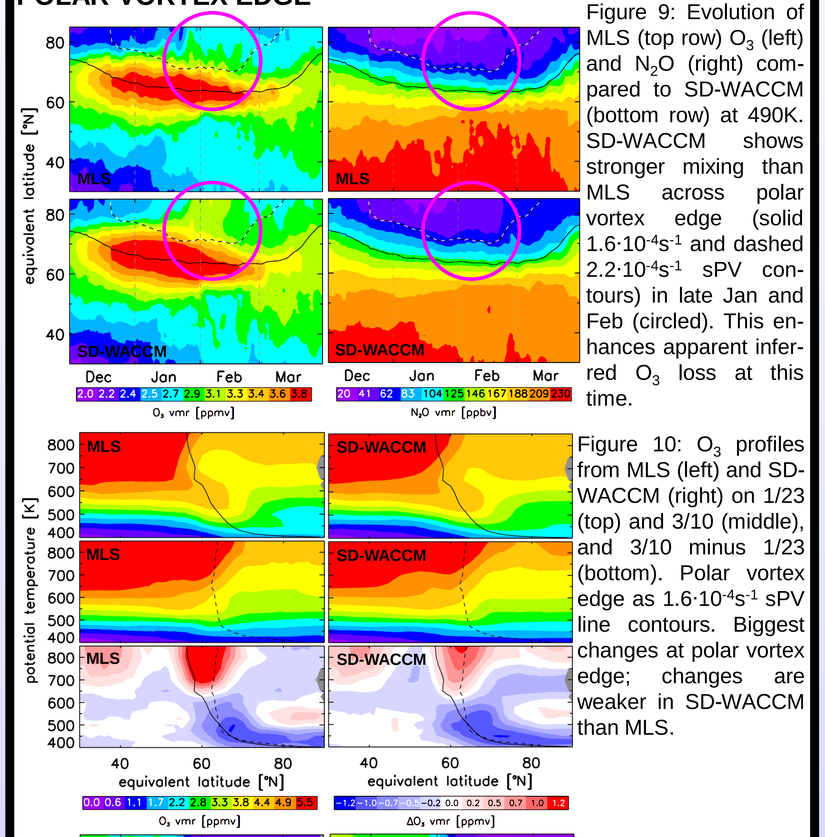


Figure 9: Evolution of MLS (top row) O_3 (left) and N_2O (right) compared to SD-WACCM (bottom row) at 490K. SD-WACCM shows stronger mixing than MLS across polar vortex edge (solid $1.6{\cdot}10^{-4}s^{-1}$ and dashed $2.2{\cdot}10^{-4}s^{-1}$ sPV contours) in late Jan and Feb (circled). This enhances apparent inferred O_3 loss at this time.

Figure 10: O_3 profiles from MLS (left) and SD-WACCM (right) on 1/23 (top) and 3/10 (middle), and 3/10 minus 1/23 (bottom). Polar vortex edge as $1.6{\cdot}10^{-4}s^{-1}$ sPV line contours. Biggest changes at polar vortex edge; changes are weaker in SD-WACCM than MLS.

Figure 11: Same as in Fig. 10, but for N_2O. SD-WACCM and MLS compare well, but SD-WACCM shows larger increase near and inside the vortex edge below 700K. This could indicate too little descent and/or too much mixing.

CONCLUSIONS

- SD-WACCM is valid for inferring O_3 loss from observations
- More accurate simulation of O_3 loss in WACCM requires further investigation of chlorine partitioning and PSC particle sizes
- Equivalent analysis for Antarctic winter needed to better investigate mixing and descent
- Future plans include O_3 loss calculations for all Arctic and Antarctic winters since 2004